

Normal ranges of modified axial lead system electrocardiogram parameters

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The normal ranges of 3 orthogonal lead electrocardiogram parameters, derived from the modified axial lead system, have been determined by computer analysis. A discussion of the clinically significant parameters is presented, and for those who may not wish to use the modified version of the axial system the calculation of ranges for the original axial system is detailed in an Appendix.

A modification to the axial orthogonal lead electrocardiogram recording system of McFee and Parungao (1961) has recently been described (Macfarlane, 1969). In order to determine the normal ranges of parameters for the modified system a group of normal subjects had 3 lead electrocardiograms analysed and interpreted by computer. This paper describes the results obtained.

Methods

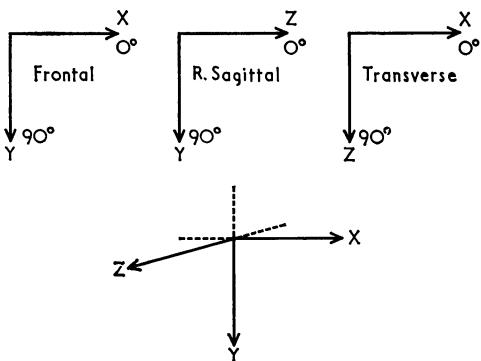
Two hundred and sixty-five normal male and female subjects whose ages ranged from 4 to 80 years were studied. Their age distribution stratified in three groups, up to 14 years, 15 to 29 years, 30 years and over, is shown in Table I. Each patient was assessed as normal on the basis of physical, radiological, and conventional 12 lead electrocardiographic examination.

Three lead electrocardiograms were tape-recorded using standard FM techniques and replayed to a PDP-8 computer for analogue to

lead by a scalar analysis of each lead individually. The onset of the QRS complex in each lead was taken as the baseline or zero value for the whole P-QRS-T complex. The method of wave recognition will be presented elsewhere in detail (Macfarlane, 1971).

All wave measurements were output to magnetic tape for analysis by a second programme which calculated means, standard deviations, and 96 per cent ranges for each parameter. If the value of a parameter was zero or did not exist — for example, an R/Q ratio when there was no Q wave, the parameter was not included in the estimation of the mean and standard deviation. Ninety-six per cent ranges were calculated, since it is well known that values of electrocardiogram parameters are not distributed normally (Simonson, 1961). Hence it is not correct to consider the range of a parameter to be the mean $\pm 2 \times$ standard deviation. In the case of the under-15 age-group with only 18 patients, one value of a parameter was removed from the lower and upper end of the range.

FIG. I *The 3 orthogonal lead reference frame used. Lead Z is directed positively to the anterior.*



digital conversion. Data were subsequently transferred to a KDF9 computer for further analysis. Approximate wave onset and termination points were obtained using the concept of spatial velocity (Stallmann and Pipberger, 1961). Thereafter the true onset and termination were found for each

As a supplement, these ranges were studied to determine those which best separated normal from abnormal as discussed below. This led to the formation of diagnostic criteria which formed the basis of a computer programme for electrocardiogram interpretation.

Electrocardiogram parameters

Fig. 1 shows the co-ordinate frame of reference used. Lead Z is directed anteriorly contrary to the recommendations of the American Heart Association Committee on Electrocardiography (1967). This was thought advisable to enable a straightforward comparison to be made with the praecordial leads V₁, V₂. In addition, with the choice of right sagittal projection as opposed to

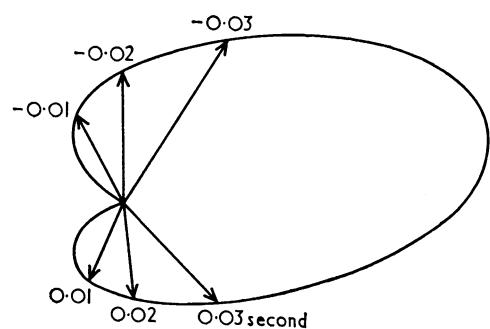


FIG. 2 Illustration of the 0.01, 0.02, 0.03 sec. vectors after QRS onset and -0.03, -0.02, -0.01 sec. vectors before QRS termination.

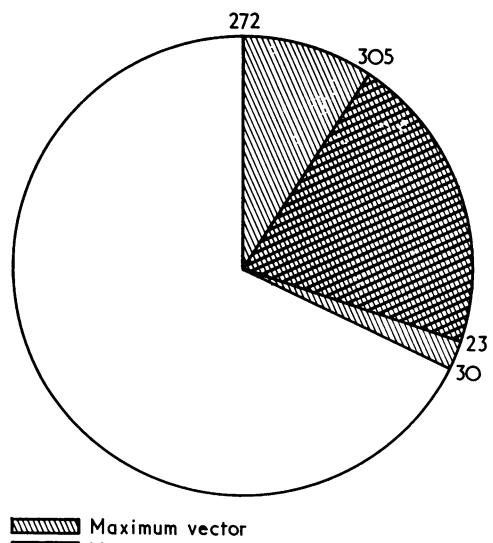


FIG. 3 Ranges of normal values of the maximum vector in the transverse plane and the projection of the maximum spatial vector on to the transverse plane.

left, the angular frame of reference was the same for each plane, frontal, right sagittal, and transverse. Angles were measured from 0°→360° in a clockwise direction (Fig. 1).

All standard scalar wave amplitudes and duration measurements were obtained. Only Q, R, and S wave durations are presented, since PR, QRS, and QT intervals correspond with 12 lead measurements. In addition time-normalized data (Draper *et al.*, 1964) were obtained for QRS and ST-T segments (see Fig. 4). In this technique the QRS or ST-T segment is divided into 8 equal time intervals and the wave amplitude determined at the end of each.

TABLE 2 Normal ranges of P, Q, R, S, ST junction, and T wave amplitudes: (a) denotes the under - 15 age-group; (b) denotes the 15 to 29 age-group; (c) denotes the over - 29 age-group. Results are expressed as mean ± standard deviation with the 96 per cent range given below

Wave	Lead		
	X	Y	Z
P	(a) 0.07±0.05 mV -0.03→0.13	0.08±0.09 -0.06→0.15	0.03±0.05 -0.05→0.09
	(b) 0.06±0.04 -0.03→0.14	0.10±0.08 -0.09→0.25	0.03±0.04 -0.05→0.11
	(c) 0.07±0.04 -0.04→0.13	0.12±0.07 -0.65→0.27	0.01±0.05 -0.08→0.09
Q	(a) 0.13±0.09 0.04→0.27	0.13±0.08 0.05→0.27	—
	(b) 0.10±0.07 0.03→0.22	0.10±0.07 0.03→0.26	—
	(c) 0.09±0.07 0.03→0.27	0.09±0.07 0.03→0.19	—
R	(a) 1.24±0.46 0.65→2.03	1.20±0.46 0.60→1.72	0.48±0.22 0.18→0.82
	(b) 1.08±0.33 0.47→1.93	1.16±0.47 0.49→2.01	0.30±0.16 0.07→0.67
	(c) 1.07±0.35 0.50→1.77	0.81±0.36 0.22→1.63	0.26±0.15 0.06→0.62
S	(a) 0.24±0.18 0.03→0.46	0.16±0.13 0.01→0.34	0.69±0.29 0.34→1.11
	(b) 0.19±0.12 0.03→0.43	0.18±0.13 0.05→0.41	0.53±0.28 0.12→1.13
	(c) 0.16±0.12 0.06→0.43	0.16±0.12 0.03→0.47	0.48±0.22 0.15→0.94
ST junction	(a) 0.02±0.04 -0.03→0.05	0.02±0.02 -0.01→0.04	0.04±0.03 0.01→0.08
	(b) 0.01±0.03 -0.04→0.08	0.02±0.04 -0.04→0.11	0.03±0.03 -0.03→0.10
	(c) 0.00±0.03 -0.06→0.07	0.02±0.04 -0.06→0.09	0.02±0.03 -0.04→0.08
T	(a) 0.42±0.20 0.22→0.75	0.26±0.15 0.11→0.59	0.12±0.12 0.02→0.39
	(b) 0.30±0.13 0.06→0.50	0.26±0.12 0.11→0.54	0.17±0.11 0.05→0.39
	(c) 0.26±0.10 0.07→0.44	0.25±0.11 0.09→0.45	0.16±0.10 0.05→0.34

TABLE 3 Normal ranges of Q, R, S wave durations. Wave onset and terminations determined individually for each lead

Wave	Lead			
		X	Y	Z
Q	(a)	0.018 ± 0.004 sec. 0.015 → 0.024	0.020 ± 0.005 0.013 → 0.024	—
	(b)	0.019 ± 0.006 0.010 → 0.027	0.019 ± 0.006 0.010 → 0.026	—
	(c)	0.017 ± 0.004 0.010 → 0.023	0.019 ± 0.010 0.009 → 0.044	—
	(a)	0.038 ± 0.009 0.029 → 0.052	0.044 ± 0.014 0.034 → 0.072	0.035 ± 0.007 0.023 → 0.045
	(b)	0.041 ± 0.010 0.029 → 0.068	0.048 ± 0.016 0.016 → 0.081	0.034 ± 0.008 0.019 → 0.048
	(c)	0.043 ± 0.013 0.028 → 0.084	0.050 ± 0.019 0.028 → 0.094	0.033 ± 0.008 0.018 → 0.053
S	(a)	0.030 ± 0.009 0.014 → 0.040	0.025 ± 0.009 0.016 → 0.040	0.038 ± 0.009 0.028 → 0.050
	(b)	0.028 ± 0.010 0.012 → 0.047	0.027 ± 0.008 0.015 → 0.040	0.042 ± 0.011 0.020 → 0.065
	(c)	0.032 ± 0.012 0.014 → 0.057	0.026 ± 0.009 0.010 → 0.045	0.043 ± 0.010 0.024 → 0.064

TABLE 5 Normal ranges of magnitude and orientation of maximal spatial vectors

Maximum spatial vector	Plane				
	F	RS	T	Amplitude	
P	(a)	43 ± 49° 321 → 78	54 ± 55 311 → 109	20 ± 42 306 → 84	0.13 ± 0.04 0.09 → 0.20
	(b)	54 ± 43 27 → 104	72 ± 51 58 → 167	26 ± 44 4 → 149	0.14 ± 0.05 0.06 → 0.26
	(c)	60 ± 39 271 → 102	88 ± 41 14 → 216	11 ± 54 2 → 120	0.16 ± 0.05 0.07 → 0.28
	(a)	45 ± 14 24 → 62	89 ± 30 39 → 124	359 ± 28 316 → 38	1.83 ± 0.54 1.11 → 2.51
	(b)	44 ± 24 17 → 73	102 ± 21 72 → 146	348 ± 21 305 → 23	1.69 ± 0.46 1.05 → 2.79
	(c)	36 ± 21 0 → 64	94 ± 31 30 → 150	354 ± 20 318 → 19	1.42 ± 0.37 0.89 → 2.30
QRS	(a)	32 ± 13 15 → 54	76 ± 21 42 → 103	12 ± 17 355 → 36	0.52 ± 0.23 0.28 → 1.03
	(b)	41 ± 20 17 → 69	59 ± 22 27 → 101	29 ± 21 349 → 78	0.45 ± 0.15 0.20 → 0.80
	(c)	43 ± 18 16 → 70	59 ± 22 25 → 92	29 ± 20 358 → 65	0.40 ± 0.13 0.18 → 0.67

Maximum P, QRS, and T vector magnitudes and orientations were calculated together with the vectors at 0.01, 0.02, and 0.03 sec. after QRS onset and -0.01, -0.02, and -0.03 sec. before QRS termination (Fig. 2). The projection of the maximum vector on to each plane and the maximum vector in each plane (not necessarily the same) were also calculated. Only the early QRS vectors were found to be of diagnostic significance in subsequent clinical studies.

The R/S, R/Q, and R/T ratios were calculated

for each lead. Time integrals were also obtained, and though these were not extensively utilized in the interpretation programme their values are presented for completeness.

Results

The results of the study are presented in Tables 2–13. Means and standard deviations together with 96 per cent ranges are given for each age-group.

TABLE 4 Normal ranges of R/Q, R/S, R/T ratios

Ratio	Lead			
	X	Y	Z	
R/Q	(a)	14.1 ± 11.3 6.7 → 26.3	13.0 ± 6.3 7.1 → 21.2	—
	(b)	17.0 ± 16.3 5.4 → 56.4	14.5 ± 16.1 3.8 → 49.8	—
	(c)	18.0 ± 17.2 5.2 → 59.1	13.0 ± 13.0 3.0 → 40.3	—
	(a)	—	—	1.0 ± 1.3 0.3 → 2.7
	(b)	—	—	0.69 ± 1.3 0.1 → 2.2
	(c)	—	—	0.68 ± 0.9 0.1 → 1.4
R/S	(a)	—	—	—
	(b)	—	—	—
	(c)	—	—	—
	(a)	3.3 ± 1.04 1.7 → 4.4	5.6 ± 3.1 2.0 → 10.7	5.6 ± 5.3 0.5 → 16.9
	(b)	3.8 ± 4.1 0.1 → 12.7	4.6 ± 2.9 0.01 → 12.9	2.4 ± 7.0 -3.5 → 8.0
	(c)	4.6 ± 3.3 0.3 → 10.2	3.4 ± 2.3 0.3 → 8.3	2.0 ± 2.8 0.7 → 6.4
R/T	(a)	—	—	—
	(b)	—	—	—
	(c)	—	—	—
	(a)	1.74 ± 0.54 0.99 → 2.41	1.33 ± 0.40 0.70 → 1.93	1.34 ± 0.45 0.81 → 2.07
	(b)	1.61 ± 0.44 1.00 → 2.64	1.24 ± 0.45 0.59 → 2.16	1.15 ± 0.34 0.52 → 1.98
	(c)	1.37 ± 0.38 0.79 → 2.29	0.91 ± 0.32 0.47 → 1.63	1.12 ± 0.33 0.59 → 1.89

TABLE 6 Normal ranges of amplitude of maximum vector in each plane. Each column is derived independently of others

Maximum planar vector	Plane			
	F	RS	T	
P	(a)	0.13 ± 0.04 mV 0.09 → 0.17	0.12 ± 0.04 0.04 → 0.19	0.09 ± 0.03 0.06 → 0.14
	(b)	0.13 ± 0.06 0.05 → 0.25	0.13 ± 0.06 0.04 → 0.26	0.08 ± 0.03 0.03 → 0.16
	(c)	0.15 ± 0.05 0.06 → 0.28	0.14 ± 0.06 0.06 → 0.27	0.08 ± 0.03 0.04 → 0.14
	(a)	1.74 ± 0.54 0.99 → 2.41	1.33 ± 0.40 0.70 → 1.93	1.34 ± 0.45 0.81 → 2.07
	(b)	1.61 ± 0.44 1.00 → 2.64	1.24 ± 0.45 0.59 → 2.16	1.15 ± 0.34 0.52 → 1.98
	(c)	1.37 ± 0.38 0.79 → 2.29	0.91 ± 0.32 0.47 → 1.63	1.12 ± 0.33 0.59 → 1.89
QRS	(a)	—	—	—
	(b)	—	—	—
	(c)	—	—	—
	(a)	0.50 ± 0.23 0.26 → 0.94	0.29 ± 0.17 0.14 → 0.59	0.44 ± 0.21 0.24 → 0.83
	(b)	0.41 ± 0.14 0.18 → 0.78	0.32 ± 0.13 0.14 → 0.62	0.35 ± 0.13 0.15 → 0.64
	(c)	0.36 ± 0.12 0.16 → 0.59	0.30 ± 0.11 0.14 → 0.54	0.31 ± 0.11 0.13 → 0.56
T	(a)	—	—	—
	(b)	—	—	—
	(c)	—	—	—
	(a)	—	—	—
	(b)	—	—	—
	(c)	—	—	—

TABLE 7 Normal ranges of orientation of maximum vectors in each plane. Each column is derived independently of others

Maximum planar vector	Plane		
	F	RS	T
P (a)	40 ± 45°	47 ± 64	21 ± 50
	340 → 70	300 → 108	314 → 101
	49 ± 42	64 ± 45	25 ± 53
	27 → 99	41 → 108	2 → 165
	62 ± 36	86 ± 41	3 ± 54
	352 → 99	1 → 231	2 → 103
QRS (a)	42 ± 14	102 ± 30	335 ± 56
	27 → 62	52 → 155	235 → 40
	45 ± 14	110 ± 33	349 ± 26
	17 → 74	64 → 209	272 → 30
	35 ± 19	109 ± 42	355 ± 24
	0 → 63	49 → 210	278 → 23
T (a)	32 ± 13	76 ± 21	12.5 ± 17
	15 → 54	46 → 106	355 → 36
	41 ± 20	58 ± 23	30 ± 21
	17 → 70	27 → 102	352 → 78
	42 ± 18	59 ± 22	29 ± 23
	15 → 68	25 → 92	357 → 71

While it is accepted that the onset of the QRS complex must occur simultaneously in all leads, there is not always simultaneous movement from the baseline in each lead. It should be noted that the Q_Y wave duration, for example, is based on a measurement from the initial deviation from the baseline in lead Y, which is not necessarily at the same instant as the first deviation of any one of the group of 3 leads. This method was adopted since it may be that 3 lead electrocardiograms are interpreted without computer assistance in which case it is easier to measure the Q wave duration, etc., in each lead separately. In practice diagnostic criteria used in subsequent work incorporated the 0.03 sec. vector, which is referred to the simultaneous (approximate) onset as determined from the QRS spatial velocity.

Table 14 shows the values of the lead strengths for the modified and unmodified axial lead systems. From these data it is possible to calculate ranges for the unmodified axial system as shown in the Appendix.

Discussion

For two reasons no further attempt was made to classify the electrocardiogram measurements by sex. Firstly this is rarely done in routine practice, and secondly such a subdivision would have reduced the numbers in each group. The total of 18 patients in the under-15 age-group is admittedly low but sufficient to emphasize the importance of

TABLE 8 Normal ranges of magnitude and orientation of the 8 time-normalized QRS vectors

Vector	Plane			Amplitude in mV
	F	RS	T	
1/8 QRS (a)	218 ± 56°	335 ± 41	120 ± 45	0.17 ± 0.10
	126 → 285	294 → 38	70 → 158	0.03 → 0.27
	211 ± 72	336 ± 45	106 ± 42	0.13 ± 0.07
	52 → 327	271 → 73	5 → 169	0.02 → 0.30
	205 ± 76	346 ± 59	117 ± 52	0.10 ± 0.05
	64 → 11	204 → 114	16 → 255	0.02 → 0.21
2/8 QRS (a)	64 ± 80	16 ± 26	69 ± 35	0.47 ± 0.20
	349 → 191	350 → 65	33 → 122	0.30 → 0.74
	26 ± 85	17 ± 36	72 ± 39	0.35 ± 0.15
	16 → 182	8 → 89	1 → 154	0.11 → 0.69
	54 ± 66	22 ± 37	62 ± 39	0.32 ± 0.18
	15 → 194	3 → 82	3 → 141	0.08 → 0.71
3/8 QRS (a)	43 ± 12	77 ± 30	10 ± 31	1.35 ± 0.49
	31 → 60	31 → 118	338 → 46	0.85 → 1.91
	39 ± 26	78 ± 29	10 ± 27	1.08 ± 0.45
	333 → 71	345 → 128	1 → 76	0.36 → 2.05
	33 ± 24	78 ± 34	7 ± 24	1.01 ± 0.33
	0 → 58	22 → 131	1 → 47	0.44 → 1.61
4/8 QRS (a)	68 ± 40	118 ± 32	315 ± 53	1.43 ± 0.49
	32 → 150	69 → 161	234 → 28	0.85 → 2.23
	55 ± 38	117 ± 27	329 ± 33	1.34 ± 0.49
	11 → 192	75 → 185	256 → 16	0.43 → 2.27
	37 ± 42	126 ± 41	329 ± 37	1.08 ± 0.46
	9 → 112	73 → 215	238 → 10	0.35 → 2.11
5/8 QRS (a)	132 ± 94°	175 ± 27	261 ± 35	0.59 ± 0.24
	357 → 264	137 → 206	218 → 311	0.32 → 0.75
	86 ± 88	163 ± 39	273 ± 40	0.65 ± 0.34
	39 → 234	84 → 238	208 → 5	0.15 → 1.36
	264 ± 114	169 ± 41	278 ± 39	0.54 ± 0.26
	81 → 64	101 → 231	210 → 350	0.21 → 1.18
6/8 QRS (a)	269 ± 72	219 ± 44	252 ± 50	0.22 ± 0.13
	156 → 52	146 → 277	186 → 334	0.06 → 0.33
	195 ± 82	189 ± 57	240 ± 58	0.23 ± 0.12
	55 → 3	85 → 290	91 → 340	0.04 ± 0.51
	358 ± 110	179 ± 55	258 ± 51	0.21 ± 0.12
	187 → 165	95 → 280	120 → 10	0.96 → 0.49
7/8 QRS (a)	20 ± 74	32 ± 64	61 ± 64	0.07 ± 0.04
	238 → 115	301 → 116	344 → 157	0.04 → 0.13
	71 ± 95	54 ± 87	44 ± 91	0.07 ± 0.04
	9 → 260	9 → 203	13 → 208	0.01 → 0.15
	55 ± 99	102 ± 94	357 ± 106	0.07 ± 0.04
	16 → 222	19 → 270	185 → 166	0.01 → 0.15
8/8 QRS (a)	50 ± 76	6 ± 37	78 ± 53	0.08 ± 0.04
	330 → 200	316 → 41	25 → 159	0.03 → 0.15
	67 ± 77	27 ± 50	67 ± 50	0.07 ± 0.04
	19 → 234	2 → 117	16 → 158	0.02 → 0.17
	60 ± 84	30 ± 60	80 ± 64	0.06 ± 0.02
	14 → 208	11 → 166	24 → 194	0.02 → 0.12

TABLE 9 Normal ranges of component amplitudes of time-normalized QRS vectors

classification by age. Gamboa and White (1968) have already published unmodified axial lead system data for children.

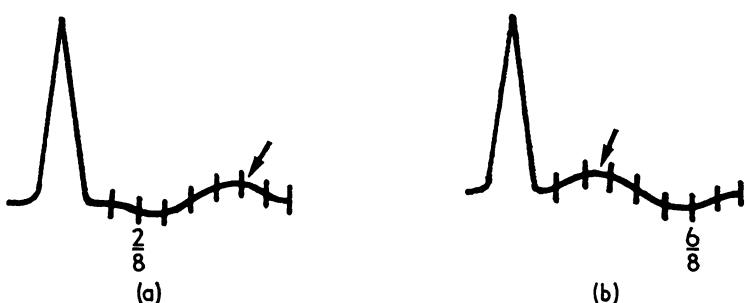
While a full selection of electrocardiogram parameters is presented, further study showed some to be of more use than others. In particular, the projection of the maximum spatial vector on to the transverse plane had a narrower range of values than the maximum vector in the plane and so proved to be the better diagnostic parameter (Fig. 3). This is of considerable significance in the visual interpretation of vectorcardiograms where a false positive diagnosis of left ventricular hypertrophy could be made on the basis of transverse plane vector orientations alone if a careful scrutiny of the vectorcardiogram is not made.

The concept of time normalization ultimately proved of great use in the diagnosis of ST-T abnormalities. Fig. 4 shows how early or late ST-T abnormalities could be overlooked if only the maximum T wave amplitude were considered. On the other hand, the 0.03 sec., etc., QRS vectors proved more useful than the time-normalized QRS vectors.

There is no doubt that the greater number of projections of the cardiac electrical activity in the 12 lead electrocardiogram may make abnormalities more apparent than in the 3 lead, but the use of computer techniques to derive the parameters presented above leads to equally accurate clinical interpretations in each case (Macfarlane, Lorimer, and Lawrie, 1971). This is of considerable importance in the application of computers to electrocardiogram interpretation, since there is an obvious saving in time for analysis compared to the 12 lead electrocardiogram.

Vector		Lead		
		X	Y	Z
1/8 QRS	(a)	-0.07 ± 0.07 mV	-0.04 ± 0.09	0.11 ± 0.08
		-0.17 → 0.03	-0.14 → 0.05	0.02 → 0.21
	(b)	-0.03 ± 0.06	-0.04 ± 0.07	0.08 ± 0.06
		-0.18 → 0.11	-0.17 → 0.12	0.0 → 0.23
	(c)	-0.03 ± 0.05	-0.01 ± 0.06	0.06 ± 0.05
		-0.14 → 0.06	-0.12 → 0.12	-0.02 → 0.16
2/8 QRS	(a)	0.17 ± 0.27	0.08 ± 0.14	0.34 ± 0.15
		-0.19 → 0.50	-0.06 → 0.24	0.16 → 0.53
	(b)	0.10 ± 0.19	0.08 ± 0.16	0.23 ± 0.13
		-0.17 → 0.55	-0.25 → 0.39	0.0 → 0.52
	(c)	0.13 ± 0.20	0.11 ± 0.13	0.19 ± 0.11
		-0.17 → 0.60	-0.12 → 0.36	0.01 → 0.44
3/8 QRS	(a)	0.92 ± 0.46	0.83 ± 0.35	0.15 ± 0.42
		0.32 → 1.60	0.42 → 1.44	-0.39 → 0.75
	(b)	0.74 ± 0.37	0.67 ± 0.38	0.07 ± 0.28
		0.07 → 1.62	-0.08 → 1.47	-0.56 → 0.54
	(c)	0.78 ± 0.30	0.53 ± 0.29	0.09 ± 0.24
		0.19 → 1.45	0.0 → 1.03	-0.45 → 0.51
4/8 QRS	(a)	0.61 ± 0.74	0.86 ± 0.42	-0.46 ± 0.53
		-0.47 → 1.73	0.27 → 1.56	-1.12 → 0.35
	(b)	0.76 ± 0.46	0.87 ± 0.49	-0.35 ± 0.36
		-0.15 → 1.61	-0.07 → 1.89	-1.09 → 0.30
	(c)	0.69 ± 0.49	0.55 ± 0.47	-0.28 ± 0.28
		0.18 → 1.63	-0.33 → 1.56	-0.78 → 0.18
5/8 QRS	(a)	-0.04 ± 0.28 mV	0.06 ± 0.30	-0.45 ± 0.19
		-0.34 → 0.42	-0.22 → 0.29	-0.68 → -0.20
	(b)	0.07 ± 0.34	0.21 ± 0.38	-0.41 ± 0.26
		-0.39 → 0.96	-0.34 → 1.26	-0.91 → 0.09
	(c)	0.07 ± 0.30	0.09 ± 0.28	-0.37 ± 0.20
		-0.33 → 0.72	-0.36 → 0.67	-0.80 → -0.02
6/8 QRS	(a)	-0.03 ± 0.10	-0.08 ± 0.11	-0.13 ± 0.15
		-0.13 → 0.15	-0.26 → 0.06	-0.27 → 0.02
	(b)	-0.05 ± 0.10	-0.03 ± 0.14	-0.14 ± 0.13
		-0.26 → 0.11	-0.27 → 0.23	-0.44 → 0.09
	(c)	-0.03 ± 0.09	0.0 ± 0.14	-0.13 ± 0.11
		-0.22 → 0.17	-0.27 → 0.28	-0.40 → 0.03
7/8 QRS	(a)	0.03 ± 0.04	0.02 ± 0.04	0.03 ± 0.04
		-0.03 → 0.08	-0.03 → 0.09	-0.02 → 0.06
	(b)	0.01 ± 0.04	0.01 ± 0.05	0.01 ± 0.04
		-0.06 → 0.08	-0.07 → 0.10	-0.07 → 0.10
	(c)	0.00 ± 0.03	0.02 ± 0.05	0.0 ± 0.04
		-0.06 → 0.07	-0.07 → 0.11	-0.09 → 0.08
8/8 QRS	(a)	0.02 ± 0.04	0.01 ± 0.02	0.05 ± 0.03
		-0.01 → 0.08	-0.03 → 0.06	0.02 → 0.08
	(b)	0.02 ± 0.04	0.02 ± 0.04	0.04 ± 0.04
		-0.04 → 0.10	-0.08 → 0.11	-0.03 → 0.13
	(c)	0.01 ± 0.03	0.02 ± 0.04	0.03 ± 0.03
		-0.06 → 0.07	-0.06 → 0.09	-0.03 → 0.01

FIG. 4 (a) Early ST-T abnormalities at approximately the 2/8 amplitude. (b) Late ST-T abnormalities at approximately the 6/8 amplitude. Neither abnormality would be detected by a check on the maximum T wave amplitude denoted by the arrow. This is not the case with the use of time-normalized data.



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Appendix

From the values of lead strengths as shown in Table 14 it is possible to convert some of the data obtained from the modified system for use with the unmodified system. This applies to wave amplitudes and vector orientations.

To convert lead Z amplitudes each value given in the Tables should be multiplied by $2.24/1.48$. Similarly, for lead X the scaling factor is $1.61/1.48$. Lead Y values do not require any correction.

For the conversion of angular data, let θ ($0 < \theta < 90^\circ$) be the angle measured by the modified system, and θ' the angle measured by the unmodified system. Then the following conversion equations are obtained:

$$\theta' \text{ frontal} = \tan^{-1} \left(\frac{1.48}{1.61} \tan \theta \right) \quad 0 < \theta < 90^\circ$$

$$\theta' \text{ R sagittal} = \tan^{-1} \left(\frac{1.48}{2.24} \tan \theta \right)$$

$$\theta' \text{ transverse} = \tan^{-1} \left(\frac{2.24}{1.61} \tan \theta \right)$$

As an example the range of the projection of the maximum QRS spatial vector (Table 5) on to the transverse plane, which is $318^\circ \rightarrow 19^\circ$ for the modified axial lead system, would be $309^\circ \rightarrow 25^\circ$ for the original axial lead system (patients over 29 years). This illustrates that angles outside the range $0 \rightarrow 90^\circ$ should be expressed as $0^\circ \pm \theta$ or $180^\circ \pm \theta$, where $0 < \theta < 90^\circ$, and the conversion made from θ to θ' so that the new value becomes $0^\circ \pm \theta'$ or $180^\circ \pm \theta'$ respectively.

It is not possible to calculate the range of vector magnitudes for the original axial system unless the corresponding individual component amplitudes of leads X, Y, and Z are known.

TABLE 10 Normal ranges of component amplitudes of time-normalized ST-T vectors

Vector	Lead			
		X	Y	Z
1/8 ST-T	(a)	0.03 ± 0.04 mV	0.02 ± 0.03	0.07 ± 0.03
		$-0.01 \rightarrow 0.09$	$-0.02 \rightarrow 0.06$	$0.04 \rightarrow 0.12$
	(b)	0.03 ± 0.04	0.03 ± 0.05	0.06 ± 0.04
		$-0.04 \rightarrow 0.11$	$-0.09 \rightarrow 0.12$	$0.0 \rightarrow 0.14$
	(c)	0.01 ± 0.04	0.02 ± 0.04	0.04 ± 0.04
		$-0.06 \rightarrow 0.09$	$-0.04 \rightarrow 0.09$	$-0.01 \rightarrow 0.11$
2/8 ST-T	(a)	0.06 ± 0.05	0.04 ± 0.04	0.07 ± 0.04
		$0.0 \rightarrow 0.13$	$-0.01 \rightarrow 0.09$	$0.02 \rightarrow 0.13$
	(b)	0.05 ± 0.04	0.05 ± 0.05	0.07 ± 0.05
		$-0.03 \rightarrow 0.13$	$-0.07 \rightarrow 0.14$	$0.0 \rightarrow 0.16$
	(c)	0.02 ± 0.05	0.03 ± 0.04	0.06 ± 0.04
		$-0.05 \rightarrow 0.12$	$-0.05 \rightarrow 0.11$	$-0.03 \rightarrow 0.14$
3/8 ST-T	(a)	0.11 ± 0.06	0.06 ± 0.06	0.08 ± 0.06
		$0.03 \rightarrow 0.18$	$-0.01 \rightarrow 0.15$	$0.02 \rightarrow 0.18$
	(b)	0.08 ± 0.06	0.07 ± 0.06	0.09 ± 0.06
		$-0.04 \rightarrow 0.21$	$-0.03 \rightarrow 0.19$	$-0.02 \rightarrow 0.24$
	(c)	0.05 ± 0.06	0.05 ± 0.06	0.07 ± 0.05
		$-0.04 \rightarrow 0.18$	$-0.03 \rightarrow 0.15$	$0.0 \rightarrow 0.18$
4/8 ST-T	(a)	0.21 ± 0.11	0.11 ± 0.09	0.10 ± 0.11
		$0.08 \rightarrow 0.38$	$0.0 \rightarrow 0.21$	$-0.04 \rightarrow 0.28$
	(b)	0.15 ± 0.09	0.12 ± 0.08	0.13 ± 0.09
		$-0.02 \rightarrow 0.33$	$-0.01 \rightarrow 0.28$	$0.0 \rightarrow 0.32$
	(c)	0.10 ± 0.08	0.10 ± 0.07	0.11 ± 0.08
		$-0.02 \rightarrow 0.30$	$-0.03 \rightarrow 0.26$	$0.0 \rightarrow 0.29$
5/8 ST-T	(a)	0.34 ± 0.16	0.20 ± 0.12	0.10 ± 0.12
		$0.17 \rightarrow 0.57$	$0.10 \rightarrow 0.41$	$0.0 \rightarrow 0.37$
	(b)	0.25 ± 0.13	0.20 ± 0.12	0.16 ± 0.11
		$0.01 \rightarrow 0.48$	$0.0 \rightarrow 0.47$	$-0.03 \rightarrow 0.39$
	(c)	0.10 ± 0.11	0.18 ± 0.11	0.14 ± 0.10
		$0.0 \rightarrow 0.37$	$0.01 \rightarrow 0.42$	$-0.02 \rightarrow 0.32$
6/8 ST-T	(a)	0.35 ± 0.17	0.24 ± 0.13	0.06 ± 0.10
		$0.21 \rightarrow 0.49$	$0.10 \rightarrow 0.42$	$-0.03 \rightarrow 0.26$
	(b)	0.27 ± 0.12	0.24 ± 0.11	0.13 ± 0.09
		$0.03 \rightarrow 0.47$	$0.07 \rightarrow 0.49$	$-0.02 \rightarrow 0.32$
	(c)	0.22 ± 0.11	0.22 ± 0.11	0.12 ± 0.09
		$0.02 \rightarrow 0.42$	$0.01 \rightarrow 0.43$	$-0.03 \rightarrow 0.31$
7/8 ST-T	(a)	0.17 ± 0.12	0.11 ± 0.06	0.05 ± 0.06
		$0.05 \rightarrow 0.33$	$0.04 \rightarrow 0.24$	$-0.03 \rightarrow 0.12$
	(b)	0.12 ± 0.08	0.12 ± 0.07	0.07 ± 0.06
		$-0.03 \rightarrow 0.26$	$-0.02 \rightarrow 0.23$	$-0.02 \rightarrow 0.19$
	(c)	0.11 ± 0.08	0.12 ± 0.07	0.07 ± 0.06
		$-0.01 \rightarrow 0.28$	$0.01 \rightarrow 0.26$	$-0.03 \rightarrow 0.21$

Tables 11, 12, 13, and 14
are overleaf.

TABLE II Normal ranges of 0.01, 0.02, 0.03 sec. vectors after QRS onset and before QRS termination

Vector	Plane			
	F	RS	T	Amplitude
0.01 sec. after QRS onset	(a) 189 ± 84°	352 ± 56	109 ± 54	0.08 ± 0.05
	65 → 298	293 → 94	30 → 160	0.02 → 0.16
	(b) 238 ± 83	339 ± 54	103 ± 57	0.07 ± 0.03
	77 → 54	263 → 95	351 → 249	0.01 → 0.14
	(c) 210 ± 80	343 ± 66	115 ± 64	0.06 ± 0.03
	57 → 9	214 → 118	44 → 253	0.01 → 0.13
0.02 sec. after QRS onset	(a) 205 ± 78	353 ± 30	102 ± 24	0.26 ± 0.10
	92 → 340	315 → 44	60 → 121	0.13 → 0.41
	(b) 234 ± 80	349 ± 36	101 ± 35	0.22 ± 0.11
	76 → 37	286 → 66	25 → 171	0.03 → 0.47
	(c) 125 ± 98	357 ± 48	100 ± 45	0.17 ± 0.09
	23 → 280	260 → 88	2 → 180	0.04 → 0.34
0.03 sec. after QRS onset	(a) 45 ± 63	31 ± 32	54 ± 38	0.61 ± 0.20
	6 → 153	1 → 84	6 → 100	0.35 → 0.90
	(b) 34 ± 61	33 ± 38	56 ± 40	0.46 ± 0.21
	18 → 149	6 → 96	354 → 154	0.17 → 1.06
	(c) 31 ± 53	38 ± 40	43 ± 40	0.46 ± 0.22
	15 → 139	12 → 103	17 → 137	0.08 → 0.88
-0.03 sec. before QRS termination	(a) 217 ± 73°	200 ± 37	244 ± 38	0.39 ± 0.21
	104 → 350	152 → 267	182 → 277	0.11 → 0.60
	(b) 156 ± 85	177 ± 50	258 ± 47	0.49 ± 0.30
	6 → 296	86 → 271	162 → 358	0.11 → 1.34
	(c) 26 ± 104	173 ± 47	266 ± 44	0.41 ± 0.22
	15 → 190	93 → 261	179 → 348	0.08 → 0.98
-0.02 sec. before QRS termination	(a) 225 ± 100	238 ± 76	270 ± 72	0.17 ± 0.12
	58 → 8	130 → 23	171 → 18	0.07 → 0.29
	(b) 197 ± 85	189 ± 64	239 ± 70	0.19 ± 0.10
	56 → 3	60 → 291	90 → 25	0.03 → 0.43
	(c) 340 ± 106	183 ± 67	255 ± 67	0.18 ± 0.10
	178 → 152	66 → 326	99 → 33	0.04 → 0.42
-0.01 sec. before QRS termination	(a) 10 ± 85	31 ± 64	65 ± 64	0.08 ± 0.04
	216 → 115	307 → 116	344 → 157	0.04 → 0.13
	(b) 58 ± 86	54 ± 84	38 ± 90	0.07 ± 0.04
	16 → 230	8 → 210	13 → 189	0.02 ± 0.17
	(c) 64 ± 96	105 ± 91	320 ± 106	0.07 ± 0.03
	15 → 220	19 → 274	145 → 121	0.02 → 0.14

TABLE I2 Normal ranges of component amplitudes of 0.01, 0.02, 0.03 vectors after QRS onset and before QRS terminations

Vector	Lead		
	X (mV)	Y	Z
0.01 sec. after QRS onset	(a) -0.02 ± 0.04	-0.02 ± 0.05	0.05 ± 0.04
	-0.09 → 0.02	-0.08 → 0.05	0.0 → 0.10
	(b) -0.01 ± 0.03	-0.02 ± 0.04	0.04 ± 0.03
	-0.07 → 0.08	-0.09 → 0.09	-0.01 → 0.11
	(c) -0.01 ± 0.03	-0.01 ± 0.04	0.02 ± 0.03
	-0.07 → 0.04	-0.09 → 0.06	-0.03 → 0.08
0.02 sec. after QRS onset	(a) -0.05 ± 0.10	-0.03 ± 0.11	0.20 ± 0.10
	-0.14 → 0.09	-0.16 → 0.13	0.10 → 0.31
	(b) -0.03 ± 0.11	-0.04 ± 0.11	0.15 ± 0.09
	-0.23 → 0.30	-0.22 → 0.25	0.01 → 0.38
	(c) -0.02 ± 0.09	0.01 ± 0.08	0.11 ± 0.08
	-0.10 → 0.12	-0.14 → 0.19	-0.01 → 0.24
0.03 sec. after QRS onset	(a) 0.31 ± 0.29	0.10 ± 0.18	0.34 ± 0.20
	-0.06 → 0.61	0.0 → 0.39	0.07 → 0.63
	(b) 0.22 ± 0.25	0.18 ± 0.19	0.23 ± 0.17
	-0.14 → 0.72	-0.16 → 0.54	-0.04 → 0.54
	(c) 0.28 ± 0.24	0.19 ± 0.17	0.18 ± 0.15
	-0.12 → 0.73	-0.13 → 0.51	-0.10 → 0.47
-0.03 sec. before QRS termination	(a) -0.09 ± 0.14	-0.05 ± 0.17	-0.29 ± 0.23
	-0.24 → 0.01	-0.28 → 0.09	-0.59 → 0
	(b) 0.01 ± 0.29	0.08 ± 0.31	-0.30 ± 0.23
	-0.39 → 0.83	-0.37 → 0.99	-0.74 → 0.02
	(c) 0.02 ± 0.21	0.05 ± 0.24	-0.28 ± 0.18
	-0.30 → 0.55	-0.37 → 0.56	-0.60 → 0.02
-0.02 sec. before QRS termination	(a) -0.02 ± 0.09	-0.05 ± 0.10	-0.07 ± 0.13
	-0.13 → 0.12	-0.15 → 0.08	-0.18 → 0.04
	(b) -0.03 ± 0.08	-0.02 ± 0.11	-0.10 ± 0.12
	-0.20 → 0.11	-0.24 → 0.19	-0.39 → 0.09
	(c) -0.02 ± 0.08	-0.01 ± 0.12	-0.10 ± 0.10
	-0.10 → 0.15	-0.23 → 0.23	-0.30 → 0.05
-0.01 sec. before QRS termination	(a) 0.02 ± 0.04	0.02 ± 0.05	0.03 ± 0.04
	-0.04 → 0.08	-0.04 → 0.09	-0.02 → 0.10
	(b) 0.01 ± 0.04	0.02 ± 0.05	0.01 ± 0.04
	-0.09 → 0.10	-0.06 → 0.10	-0.08 → 0.09
	(c) 0.0 ± 0.03	0.02 ± 0.05	0.0 ± 0.04
	-0.06 → 0.08	-0.07 → 0.11	-0.08 → 0.08

TABLE I3 Normal range of the time integrals
SA QRS, SA T, SA ST (area under the
*QRS, T, ST waves, respectively). S VG, the
spatial ventricular gradient, is obtained by
summing other three time integrals*

Vector	Lead			
		X	Y	Z
SA QRS	(a)	$23.3 \pm 14.8 \mu\text{V sec.}$ $8.5 \rightarrow 49.6$	25.3 ± 10.8 $13.1 \rightarrow 45.0$	-2.3 ± 11.4 $-17.8 \rightarrow 16.4$
	(b)	23.2 ± 9.9 $2.2 \rightarrow 46.2$	27.6 ± 12.4 $4.9 \rightarrow 51.8$	-3.5 ± 9.8 $-23.2 \rightarrow 14.3$
	(c)	23.9 ± 9.7 $9.7 \rightarrow 42.4$	24.5 ± 12.6 $4.7 \rightarrow 48.4$	-4.2 ± 8.2 $-23.9 \rightarrow 9.9$
SA T	(a)	37.5 ± 15.9 $21.6 \rightarrow 69.9$	25.2 ± 14.7 $9.7 \rightarrow 49.8$	14.1 ± 14.3 $1.3 \rightarrow 42.6$
	(b)	30.4 ± 14.9 $2.2 \rightarrow 62.9$	27.3 ± 14.0 $4.8 \rightarrow 62.0$	21.7 ± 14.8 $-2.6 \rightarrow 52.8$
	(c)	23.6 ± 13.0 $1.4 \rightarrow 50.2$	23.3 ± 13.2 $1.1 \rightarrow 48.5$	18.5 ± 13.0 $-2.3 \rightarrow 44.5$
SA ST	(a)	2.2 ± 4.0 $-0.4 \rightarrow 4.6$	1.2 ± 1.2 $-0.4 \rightarrow 3.6$	2.8 ± 1.5 $0.6 \rightarrow 4.9$
	(b)	1.3 ± 2.2 $-2.6 \rightarrow 5.8$	1.5 ± 3.0 $-5.0 \rightarrow 10.7$	2.7 ± 2.3 $-0.7 \rightarrow 9.1$
	(c)	0.4 ± 1.7 $-3.3 \rightarrow 4.3$	0.9 ± 1.7 $-1.8 \rightarrow 4.9$	2.2 ± 2.0 $-0.6 \rightarrow 7.1$
S VG	(a)	52.4 ± 14.7 $38.1 \rightarrow 72.1$	48.4 ± 19.4 $30.3 \rightarrow 75.8$	14.6 ± 17.8 $-7.5 \rightarrow 40.6$
	(b)	53.5 ± 18.8 $18.8 \rightarrow 87.2$	55.4 ± 21.0 $19.6 \rightarrow 97.3$	20.8 ± 19.4 $-12.8 \rightarrow 64.9$
	(c)	47.6 ± 17.6 $17.3 \rightarrow 83.3$	48.4 ± 21.3 $11.2 \rightarrow 91.1$	16.4 ± 17.3 $-14.1 \rightarrow 49.5$

TABLE I4 Lead strengths of the modified and original axial lead system

	X	Y	Z
Axial	1.61	1.48	2.24 mV/cm.
Modified axial	1.48	1.48	1.48